further comprising:

providing a driving frequency of a driving voltage of the optical liquid crystal modulator of greater than 50 kHz.

REMARKS

This Preliminary Amendment cancels, without prejudice, original claims 1-12 in the underlying PCT Application No. PCT/EP00/08261, and adds new claims 13-26. The new claims conform the claims to U.S. Patent and Trademark Office rules and do not add new matter to the application.

The amendments to the specification and abstract reflected in the substitute specification are to conform the specification and abstract to U.S. Patent and Trademark Office rules and to introduce changes made in the underlying PCT application, and do not introduce new matter into the application.

The underlying PCT Application No. PCT/EP00/08261 includes an International Search Report, issued December 22, 2000, a copy of which is included. The Search Report includes a list of documents that were considered by the Examiner in the underlying PCT application.

Applicants assert that the present invention is new, non-obvious, and useful. Prompt consideration and allowance of the claims are respectfully requested.

Respectfully Submitted,

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DEVICE AND METHOD FOR THE TEMPERATURE-INDEPENDENT OPERATION OF ELECTRO-OPTICAL SWITCHES ON THE BASIS OF FERROELECTRIC LIQUID CRYSTALS HAVING A DEFORMED HELIX

Field of the Invention

The present invention is directed to a device[according to the definition of the species in Claim 1 and to a method according to the definition of the species in Claim 6] for the temperature-independent operation of electro-optical switches on the basis of ferroelectric liquid crystals having a deformed helix.

Background Information

For some 20 years now, optical liquid crystals have fundamentally changed display technology. As economically priced light valves, they are also often used in the switching of the optical flow of information. The development of ferroelectric liquid crystals has moved switching times into the microsecond range. However, the fact that most of a liquid crystal's physical parameters are highly temperature dependent is still causing problems. Many technical instruments require that the components exhibit the same properties within a broad temperature range. In vehicle construction, in particular, temperature requirements are from -30° C through +80° C. Optical overload-protection switches in open-air video-monitoring systems can also be exposed to such temperatures.

Examples of other applications are birefringent interference filters, which are spectrally tuned with the aid of liquid crystals (C. BARTA, et al., Crystal Optical Interference Filter, European Patent 0 907 089 A2).

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MARKED UP VERSION OF SPECIFICATION

So-called optically or electrically addressable, spatially resolving liquid crystal modulators (OASLM, EASLM), used to convert incoherent image information into coherent image information, were only able to be operated in [known]conventional methods heretofore within narrow temperature ranges, since their switching times vary considerably in response to temperature.

[The object]Summary of the Invention

The present invention [is, therefore, to alleviate the above-described disadvantages and to provide, in particular, a]provides device and a method which will substantially reduce temperature-dependent influences and attendant long switching times.

[This objective is achieved by a device having the features of Claim 1 and by a method having the features of Claim 6.

In accordance with the]The present invention[,]further provides a device and a method[are provided,] where ferroelectric liquid crystals exhibit temperature-independent and very short switching times, within a broad range, and, therefore, can be used [quite advantageously]for optical open-air switches and in vehicles.

The present invention [advantageously]further provides for an optical liquid crystal modulator to be used, where the ferroelectric liquid crystals have a DHF mode and are preferably operated within a range of the electric field of more than 20V/μm. As a result, within a frequency range substantially above 50 kHZ, the modulator has a temperature-independent and extremely low response time.

[On the basis of preferred exemplary embodiments and with reference to the enclosed drawing, the present invention

MARKED UP VERSION OF SPECIFICATION

is described in greater detail in the following. The figures show:

Figure 1: The] Brief Description of the Drawings

Figure 1 shows the dependence of electric field E_c, necessary for complete winding of the helix, on the switching frequency f at T = 20.0°C, the measurement being performed on a 2.0 μm thick cell in the liquid crystalline mixture FLC-388, and the helical pitch Po, at a temperature T = 20.0°C, having the value of 0.22 μm, according to an embodiment of the present invention;

Figure 2[:] [T]shows the dependence of switching time τ of effective tilt angle θ_{eff} and of contrast ratio CR on the frequency of the electric field[. L], having layer thickness d=1.8 μm, [ ]20 V_{pp}, T=35°C, according to an embodiment of the present invention; and

Figure 3[:] [T]shows the temperature dependence of switching time $\tau_{0.1-0.9}$ in the DHF mode at a frequency f = 130 kHz and [ ]E = ±15 V/μm (curve 1) and when switching the completely unwound state (E > E_u) at f=10 kHz and [ ]E = ±15 V/μm (curve 2), the temperature dependence of tilt angle θ in the DHF mode at f = 130 kHz and [ ]E = ±15 V/μm (measuring curve 3) and in the unwound state at f = 10 kHz and E = 15 V/μm (curve 4).

[Summary of the Invention] Detailed Description

The present invention employs ferroelectric liquid crystals for modulating light in liquid crystal

modulators, whose design, in particular external electrodes made [especially]of transparent material[, and whose cells are well known to one skilled in the art in this field, so that there is no need to describe the mechanical and electrical set-up in greater detail].

Ferroelectric liquid crystals are used, whose helix has a small pitch (< 300 μm) and is able to be continuously deformed through application of a small electric field (so-called DHF mode). This DHF mode [makes it possible to]allows for continuous[ly vary]varying of the effective tilt angle θ_{eff} and the effective birefringence Δn_{eff} at low voltages (< 5V) and short switching times (< 1ms). The effective tilt angle [is]can be equivalent in size to half of the angle of rotation of the indicatrix of the liquid crystal in the electric field; i.e., the greater the effective tilt angle is, the more intense the rotation of the indicatrix of the liquid crystal.

Since optical liquid crystal modulators are designed on the basis of the DHF mode as [lambda/2]$\lambda/2$ magnification plates which rotate in the electric field, a single pass through the plate requires tilt angles of $\pm$ 22.5 degrees in order to completely extinguish polarized light in the switching state "OFF" and obtain full transparency in the switching state "ON".

The electric field E_U, which is required for complete winding of the helix and which thereby induces the desired tilt angle, is relatively small at low frequencies (Figure 1, E_U ~0.5 through 1 V/μm at frequencies f smaller than 1 kHz). At higher frequencies, [this critical]the field strength increases; in addition, the tilt angle also decreases[; see]. This may be seen in Figures 1 and 2.

At frequencies above 50 kHz, fields E_U> 20 V/μm are necessary in order to completely unwind the helix. Thus,

the region in which the DHF effect can be utilized is shifted toward higher fields.

Since higher fields [are disadvantageous due] lead to [the] higher voltages on the liquid crystal and, moreover, lead to smaller tilt angles, till now, this region was not considered to be interesting from a technical standpoint.

In the exemplary embodiment according to the present invention, Figure 1 depicts the dependency of electric field E_c, necessary for a complete winding of the helix, on switching frequency f at T = 20.0°C. The measurement was performed on a 2.0 μm thick cell in a self-produced liquid crystalline mixture FLC-388. The helical pitch Po amounts to 0.22 μm at a temperature of T = 20.0° C. In addition, at a temperature of approximately T = 20.0° C, i.e., at about room temperature, the helical pitch Po lies within a range of 0.1 to 0.5.

With higher frequencies, however, the response time τ [is] can be lowered by more than one order of magnitude, while tilt angle θ remains virtually constant up to very high frequencies [(] See Figure 2 [)] . Thus, it may be that the contrast ratio and the birefringence also drop with the switching time, but acceptable values are still achieved for applications.

In the exemplary embodiment according to the present invention, Figure 2 illustrates the dependency of switching time τ of the effective tilt angle θ_{eff} and of the contrast ratio CR on the frequency of the electric field at a layer thickness of [ ]d = 1.8 μm and 20 V_{pp}, as well as at a temperature of T = 35°C.

[As an example] In the exemplary embodiment according to the present invention, Figure 3 depicts a measurement of

response time τ as a function of the temperature for such a liquid crystal system. While at 10 kHz, response time τ is heavily temperature-dependent for an operation of the liquid crystal (curve 2), at an operating frequency of 130 kHz, it is not only very short, but also absolutely thermally stable (curve 1). In this context, the effective tilt angle changes only slightly, and the temperature dependency (curve 3 + 4) does not become significant until temperatures greater than 50°C.

By extensively optimizing the mixtures, as expected, a high-speed liquid crystal switch is able to be developed in accordance with the present invention for an application range of -20 through 80° C.

Abstract

In order to substantially reduce temperature-dependent influences and attendant long switching times in the case of an optical liquid crystal modulator having at least one ferroelectric liquid crystal and in a method for operating an optical liquid crystal modulator, [it is provided for]the ferroelectric liquid crystals are provided to have a DHF mode and to exhibit an operating range of [the]an electric field of more than 20 V/μm at the location of the liquid crystal.